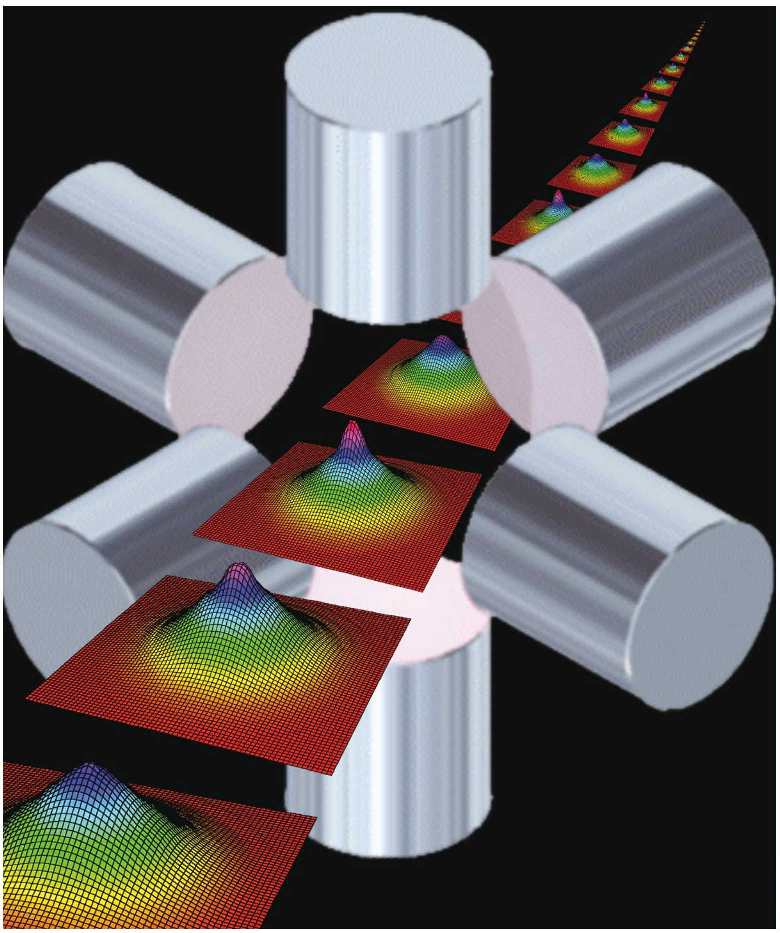
VOL. 8 NO. 2 SUMMER 2001

MICROGRAVITY NEWS

MICROGRAVITY RESEARCH PROGRAM

Laser Cooling Puts the Freeze on Fast-Moving Atoms



Slowing down atoms enough to produce a Bose-Einstein condensate is a tricky undertaking that involves the trapping and cooling of atoms to extremely low temperatures. (In this artist's rendering, time progresses from the lower left to the upper right corner. Six cylinder-shaped magnets keep the atoms in place as they cool to a condensate, shown as the central peaks in this series of images.)

At the beginning of the 20th century, scientists armed with the latest discoveries from the fields of chemistry, electricity and magnetism, radioactivity, and quantum mechanics were on the verge of uncovering a number of major mysteries regarding the atomic world. They understood that atoms were made of even smaller particles of varying masses that carried both positive and negative charges, that light given off when an electric current passes through the atoms of a gaseous substance produces a unique pattern of dark and colored bands (and

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Inside...

Profile:

National Aeronautics and Space Administration
Physical Sciences Division

From the Director...

It should no longer be any surprise to the researchers in our Physical Sciences Program that the International Space Station fiscal troubles have tremendously impacted the timetable of its scientific mission. In the face of a nearly $1-billion reduction in the Office of Biological and Physical Research (OBPR) International Space Station utilization budget, the physical sciences research plans had to be drastically altered, including reducing and delaying the availability of on-orbit resources.

To maximize the research productivity of the ISS while the prerequisite building and deploying of the space platform continues, the agency is deferring the build-up of more expensive and resource-taxing space-based research facilities. The resulting research program content still contains facilities for macromolecular and cellular biotechnology, fundamental physics, fluid physics, and materials science. At this time, the previously scheduled ISS Combustion Science Facility is no longer part of the funded program in fiscal year 2002, but the potential of an infusion of additional funding through congressional budgetary action keeps alive the possibility of retaining some level of combustion flight research. In addition, the flight research programs in fluid physics and materials science have also been considerably curtailed, and a total of 60 already-selected flight and flight-definition investigations in these two disciplines, as well as in combustion, may be returned to the ground-based research program. If necessary, these 60 principal investigators will be asked to carry out the balance of their funding period to redefine their research and resubmit proposals to a future NASA Research Announcement.

The restructured funding described above affects only the part of the OBPR budget that funds the development of on-orbit research facilities and their operation; the part of the budget dedicated to funding the principal investigators in the Physical Sciences Division has not been affected. The directions of the research program, however, cannot remain unaltered: the potential reduction in the ISS crew complement and the cutback in the available number of discipline-dedicated research facilities require a profound reassessment of the breadth of the program. Two task groups from the National Research Council are currently assessing the ISS research program in general and the physical sciences research in particular, and they will provide guidance for a realignment of our scientific direction.

In the meantime, we are striving to assemble a program that will synergistically integrate the physical sciences with the biological sciences to yield a unique new research thrust to explore the interface between inert and living complex systems. By using the low-gravity environment and further refining advanced experimental tools in molecular physics, chemistry, and biology, we intend to implement a program that is as valuable as the original baseline prior to the funding cut. By substituting a more focused and integrated research program for the original disconnected, multi-disciplinary approach, we believe that we will improve the quality of the research as we reduce the quantity.

We will take advantage of the next three to four years required to complete the ISS assembly to refine a new set of flight-based investigations that will optimize the scientific and technological productivity of the ISS. Prominently featured will be advanced cellular biotechnology investigations in three-dimensional tissue engineering, fundamental cell biology research, colloidal physics and self-assembly processes, cutting-edge advances in Bose-Einstein condensate research, microgravity fluid-based research to advance space exploration technologies, and fundamental condensed matter physics and advanced materials. This peer-reviewed research will be the best that any research funding agency can wish to offer.

Eugene Trinh

Microgravity News, It Is A-Changin'

When *Microgravity News* subscribers go to their mailboxes late this year, they may be surprised to find a new publication. "*Space Research*? What the heck is this?" they might wonder. Well, it's what *Microgravity News* has always been — and a lot more.

Microgravity News will become Space Research, an enterprise-wide publication, in fall 2001. This expansion will be one more evolution for a newsletter with a history of making itself over to fit the needs of a changing program.

With the fall 2001 issue, *Microgravity News* will become *Space Research*, and its coverage will expand to include the activities of the entire Office of Biological and Physical Research (OBPR) Enterprise. The expanded newsletter will offer stories and updates concerning research supported not only by NASA's Physical Sciences Division but also by the Fundamental Biology Division, the Bioastronautics Division, and the commercial branch of the OBPR. This expansion will bring new topics to the newsletter, such as determining the effects of microgravity on humans and the development of countermeasures to ensure crew health for long-term space missions, understanding how plants adapt to a low-gravity environment and what that might teach us about improving agriculture on Earth, and using space to find clues to how life evolved on Earth and perhaps on other planets.

Most publications mirror their times, and *Microgravity News* is no exception. Throughout its history, the newsletter has reflected the goals, accomplishments, and issues of the NASA program it represents. So it is fitting, as the Microgravity Research Program is asked to take on new goals and challenges under the guidance of the recently created OBPR Enterprise, that *Microgravity News* be asked to take on a new mission as well. Indeed, the history of the newsletter has been one of successful evolution in order to keep pace with a changing and growing program.

Starting Out

Both *Microgravity News* and the current microgravity program have roots in a NASA project called PACE, or Physics and Chemistry Experiments in Space. Originally starting with just 14 spaceflight experiments, the PACE program needed a quarterly newsletter to track the progress of those experiments and the program itself for the small community of involved and interested scientists and NASA managers and engineers. The Universities Space Research Association in Boulder, Colorado, was contracted to produce the newsletter, and the first issue of *PACE* appeared in 1984. That was the same year that PACE, managed from Langley Research Center in Hampton, Virginia, made a significant move to a new programmatic home within the recently formed Microgravity Science and Applications Division (MSAD) at NASA headquarters. Although a part of MSAD, PACE remained a distinct program, and the newsletter *PACE* continued.

In 1988, the PACE program and the newsletter took another turn together. The MSAD program had expanded, its four major disciplines (biotechnology, combustion science, fluid physics, and materials science) were developing, competitive programs for funding ground-based and flight research were being established, and planning was under way for a decade of shuttle missions dedicated to microgravity science experiments. The 14 experiments of the PACE program were merged with those of the MSAD program. The newsletter was reincarnated as *Microgravity News*, and Bionetics Corporation, in Washington, D.C., took over its production.

Microgravity News reported on the activities of the entire division. It presented developments in the growing disciplines, described the progress and plans for experiments in the ground and flight programs, announced upcoming conferences, and reported on the success of the early microgravity shuttle missions: the first and second International Microgravity Laboratory missions (IML–1 and IML–2), the first United States Microgravity Laboratory mission (USML–1), and the first and second United States Microgravity Payload missions (USMP–1 and USMP–2). With the increase in activities to report, *Microgravity News* expanded from the PACE newsletter's six pages to 16.

Archived issues of *Microgravity News* back to 1993 are available on the web at *http://mgnews.msfc.nasa.gov*

In Full Stride

By the mid-1990s, the division's outreach and education efforts were undergoing some changes, and management

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Bridging Disciplines and Cultures to Discuss Microgravity

Almost 200 scientists representing 82 universities and 12 countries gathered in Pasadena, California, in May to share their latest research related to microgravity and the space environment. The Second Pan-Pacific Basin Workshop on Microgravity Sciences was a four-day opportunity for researchers, hailing mostly from countries that border the Pacific Ocean, to learn from one another about studies ranging from fundamental research in physical, chemical, and biological processes to cross-discipline research and applied technology innovations. They also learned firsthand how education and outreach can play a key role in explaining the benefits of their work to large numbers of people.

> "Scientific advances . . . come from the united effort of many people in many separate disciplines, each contributing his or her individual expertise."
>
> — Steven Sample, chairman of the Association of Pacific Rim Universities

This largest gathering ever of microgravity scientists from the Pacific Rim was hosted by the Association of Pacific Rim Universities (APRU), the National Society of Microgravity Science and Application of China, and the Japan Society of Microgravity Application. Other participating organizations included NASA, the National Space Development Agency of Japan, the Chinese Academy of Sciences, the Canadian Space Agency, and the Russian Space Agency.

Steven Sample, chairman of the APRU and president of the University of Southern California, explained the importance of this unique gathering: "Science issues that affect one part of the Pacific Rim affect all of us. Also, we all recognize the common basic need for increased education and knowledge about the effects of gravity and microgravity in countless areas of our lives." Sample defined the workshop as a key arena for some of the best minds in universities thousands of miles apart to address research questions that affect all participating communities.

"Scientific advances do not occur in a vacuum. They are no longer the result of one person working alone," Sample said. "Instead, they come from the united effort of many people in many separate disciplines, each contributing his or her individual expertise." Sample predicted that the knowledge shared during the conference would help set the stage for the future growth and direction of many fields in science.

The Hot Pursuit of Supercool Science

Some of that knowledge came from internationally renowned scientists who served as plenary speakers. The first such speaker was David Lee, a physicist from Cornell University, who discovered the superfluid state of helium-3 with colleagues Robert Richardson and Douglas Osheroff. Their discovery was recognized with the Nobel Prize in physics in 1996. Lee's talk covered his pursuit of this unusual state of matter, which occurs when helium-3 (the isotope of helium with two protons and one neutron) is cooled to 2 millikelvins above absolute zero (-273.15°C). In a superfluid state, helium-3 atoms suddenly lose all their randomness and all inner friction, so the fluid exhibits such effects as flowing through holes so small that they are impenetrable even to fluids with extremely low viscosity. Lee and his research team were tenacious in their pursuit of finding this state of matter, even after countless other physicists had long given up. Their success brought to the world a second superfluid substance that may one day help scientists better understand how the universe was formed.

Other plenary speakers included scientists in several disciplines. Materials science advances were discussed by Taketoshi Hibiya, of NEC Corporation, who spoke on materials processing, thermophysical properties, and heat and mass transfer research being conducted in Japan; and by Richard Weber, of Research Containerless Inc., who spoke on crystallization and glass formation in nonequilibrium liquids.

Talks on biotechnology included Tulane University researcher Timothy Hammond's discussion of advances in his renal cell gene expression research (see profile, page 23) and a presentation by Bert Kohlmann, of EARTH University, in Costa Rica, on efforts to determine the structure of a target enzyme that is associated with Chagas' disease. In addition, Mei-Fu Feng, of the Chinese Academy of Sciences, gave an update on biotechnology research and hardware in China.

Discussing fundamental physics research were Randall Hulet, of Rice University; Masami Ishikawa, of Mitsubishi Research Institute, Inc.; and Qiu Sheng Liu, of the Chinese Academy of Sciences. Hulet has been trapping lithium-6 atoms to create a Fermi gas, and Ishikawa has been measuring the thermophysical properties of refractory metals using an electrostatic levitation furnace. Liu gave an overview of ground-based and flight experiments in fundamental physics conducted in China.

Conference Within a Conference

In fact, fundamental physics was a major theme at the workshop, as the annual meeting for investigators

Charles Elachi, new director of the Jet Propulsion Laboratory, describes how fundamental physics, a major theme at the workshop, fits into the facility's plans for space exploration.

in NASA's microgravity fundamental physics program was held as part of the workshop. Breakout sessions for the meeting featured information on such pursuits as exploring biological questions, using liquid helium as a test bed for fundamental theories, and observing quantum behavior in clouds of atoms cooled to within a millionth of a degree of absolute zero.

This research in fundamental physics, managed by Mark C. Lee, of NASA headquarters, is primarily conducted through the Jet Propulsion Laboratory (JPL). JPL's newly installed director, Charles Elachi, described at the conference banquet how the fundamental physics program fits into the facility's ambitious plans for space exploration. Elachi described, for example, how Mars exploration has progressed from the mindset of being "lucky to get there" to planning missions for collecting samples, thanks to contributions from fundamental physicists.

Beyond the Fundamentals

In addition to fundamental physicists, investigators in other areas of microgravity research presented their work in three parallel breakout sessions that were grouped by subdiscipline topics. These topics included astrobiology and Mars exploration, biotechnology, colloids and pattern formation, combustion and chemical reaction, crystal growth and solidification processes, and experimental techniques. Other topics were instability of thermocapillary flow, life sciences, multiphase flow and transport processes, nanostructure formation, and thermophysical properties.

A few of the scientists shared their work with yet a broader audience during two satellite broadcast sessions held at the California Science Center, in Los Angeles, California. (See "Outreach Through Time Travel," page 16.) The first was geared toward encouraging young people to go into careers in science or mathematics. For this event, the science center hosted more than 100 local high school students and three panelists (a materials scientist, a biologist, and a physician who is a former astronaut). Students at the location, as well as another 200 students at three other science centers across the country, saw presentations by the panelists and then asked them questions about their research and space travel.

The second session was geared toward building interest in microgravity research among the general public. The session featured presentations on atomic clocks and combustion research and firsthand accounts of travel on a space shuttle. Viewers at two other United States science centers and at Flinders University in Adelaide, Australia, could see the presentations in real time and then ask questions of the panelists, a fundamental physicist, a combustion scientist, and a Japanese physician who is currently an astronaut. Participants at both sessions also viewed a short video featuring conversations with students and laypeople from countries around the Pan-Pacific Basin about their perspectives on space and space travel.

These education and outreach sessions supported the purpose of the conference, which was to go beyond cultural differences to advance microgravity research and promote the understanding of its importance. As Sample noted, "All these [cultural] differences can be and often are obstacles to communication and understanding, but it's important to remember that people on both sides of the Pacific share quite similar fundamental ideals and goals: to build better societies. And these goals can't be reached without building better-educated societies and without the open sharing of knowledge." This large-scale sharing among microgravity researchers in the Pan-Pacific Basin, which began in 1999 in Japan with the first microgravity workshop in the series, is planned to continue in 2003.

The outreach session brought together an international mix of microgravity scientists and members of the public to learn how microgravity research in combustion, atomic clocks, and life sciences relates to common visions and concerns about science and space travel.

Cells Are the Focus at Conference

The more than 200 government, university, and medical center scientists, as well as representatives from commercial cell culture enterprises, who attended the 2001 NASA Cell Science Conference and Annual Investigators' Working Group Meeting had a new experience: for the first time, the conference represented a collaboration between the Cellular Biotechnology Program and the Fundamental Space Biology Program.

The conference, which was held in Houston, Texas, March 6–8, normally serves as the annual working group meeting for principal investigators (PIs) in the Cellular Biotechnology Program. The investigators' working group meeting has served since 1994 as an annual review of biotechnology research funded by the Physical Sciences Division through NASA Research Announcements (NRAs). This year the meeting was expanded to include PIs from the Fundamental Space Biology Program. The goal of bringing together these two groups was to promote dialogue among researchers in different NASA divisions. As such, the conference was sponsored by both the Cellular Biotechnology Program, based at Johnson Space Center in Houston, Texas, and the Fundamental Space Biology Program at Ames Research Center (ARC) in Moffett Field, California, in cooperation with their respective divisions (the Physical Sciences Division and the Fundamental Space Biology Division) of the Office of Biological and Physical Research (OBPR) at NASA headquarters.

The two divisions became part of a new enterprise when the OBPR was created during NASA's restructuring in the fall of 2000. (See the Fall 2000 issue of *Microgravity News*.) The purpose of the restructuring was to take advantage of the synergy present in the various research disciplines to better meet the challenges facing NASA in its future missions. In the same spirit, the 2001 NASA Cell Science Conference brought together scientists from these two different NASA divisions with research in related areas to present their work and discuss their findings with their colleagues, for the benefit of all concerned.

This theme-oriented approach to research was a hallmark of the conference. It reflects the increasing cooperation among divisions, disciplines, and various branches of disciplines at NASA. Nancy Searby, of ARC, highlighted this essential cooperation in her opening remarks on the first day of the conference. Searby noted that although researchers might be in different physical locations and working under different divisions, they all receive their funding from NASA. She pointed out that the two groups must work together to advance science.

> This kind of interaction is a promising indicator of the progress to date in forging an interdisciplinary, integrated approach to science.

In fact, the Cellular Biotechnology Program and the Fundamental Space Biology Program are already in position to help one another. The Cellular Biotechnology Program uses the microgravity environment of low Earth orbit to provide a unique cell culture setting that supports three-dimensional tissue growth for the development of human disease models, drugs and vaccines, and possibly organs and tissues for transplantation. Such tissue growth occurs as the result of complex interactions between the cells in the culture and between the cells and their environment.

The Fundamental Biology Program is charged with enhancing the understanding of fundamental biological processes, and it also uses the microgravity environment to carry out this charge. Studies to achieve the program's goal include examining how spaceflight affects biological structure and function; what roles the genome and cellular structures play in sensing gravity; and whether the normal development of cells, systems, and organisms depends on gravitational forces, among other things. With such closely linked research objectives in the two programs, discoveries made in one area of research can support or drive additional research in both disciplines.

Getting Down to Business

Discussing funding for such research available through the Cellular Biotechnology Program was Neal Pellis, manager of the program. (See the Biotechnology NRA section of the Science Program Report, page 12.) The big NRA news is that NASA will be converting to a new NRA structure. There will be one annual NRA that will include all of the disciplines, with staggered due dates for proposals for each of the disciplines. The NRA will also contain special sections that will address goal-oriented initiatives requiring cross-disciplinary research. No dates have yet been set for the Cellular Biotechnology Program portion of the NRA.

Budget cuts were a topic of major concern, and Pellis remarked that all cellular biotechnology researchers could expect a five percent cut in their research budgets, but that there were no plans for further reductions.

Pellis reiterated the need for researchers to use in a timely manner the money allocated to them by NASA, because any money that appears to be unexpended could be taken back to be used for other purposes.

Another tip provided to researchers by Pellis was the need to publicize their findings. Said Pellis, "The greatest leverage with entities in NASA is physical (i.e., printed) evidence of how the money is being spent. That is, show product for the money." In addition, Pellis reminded researchers who write proposals to upgrade their ground-based research to flight-definition experiments that the experiments will be assessed for their relevance, especially to humans and terrestrial life, and their cost.

There are also other assessment factors, and cellular biotechnology experiments have some advantages when it comes to flight prioritization during the assembly period of the International Space Station (ISS). For example, Pellis noted that most of the cellular biotechnology hardware is "not big or heavy," so it can be flown on shuttle flights that are primarily designated for carrying assembly pieces to the space station. In addition, incubator-style experiments require little or no crewmember time, which must be devoted to working on the station at this point in the station's lifespan. Pellis also cautioned that there wouldn't be a steady supply of power on the station during some parts of the assembly phase. However, if cellular biotechnology researchers can stay within the constraints presented by assembly of the ISS, they have a good chance of getting their experiments flown.

Additionally, Pellis advised PIs to maximize throughput, meaning that they should design their flight experiments to obtain as much usable data as possible from their time aboard the space station. Producing quality research that is of value to the scientific community and the general public will reinforce the importance of the space station.

Also discussing the importance of quality research was John Hines, of ARC, who spoke for the Fundamental Space Biology Division. He noted that the research emphasis in fundamental space biology is on cellular and molecular biology and on genetics and genomics (the study of genes and their function). These areas are being funded under the most recent ground-based NRA for the division, for which funding selections were made in May 2001. Currently, the Fundamental Space Biology Program is also facing budget cuts, but eventually, when the budget allows, the program would like to create additional flight opportunities for model organisms. As in the Physical Sciences Division, Fundamental Space Biology Division NRAs will now be released on an annual basis, beginning with fiscal year 2002. Updates on the annual NRA and a PI handbook are available from the Fundamental Space Biology web site, ***http://fundbio.arc.nasa.gov***.

Physical Forces Drive Biological Systems

In addition to all the programmatic and budgetary issues discussed, the primary reason for bringing all of these researchers together at the conference was so that they could learn about each other's work. The majority of the conference's agenda was devoted to PIs, currently funded by either division, presenting their most recent advances. Research presentations were divided into eight categories: biological response to physical forces, cell culture technology, cell movement and the cytoskeleton (the protein fibers composing the structural framework of a cell), models in lower organisms, proliferation and differentiation, gene expression, tissue modeling, and immunology. Researchers from both the Cellular Biotechnology Program and the Fundamental Space Biology Program were represented in each of the categories. As a result, scientists from the two programs were able to listen to and discuss how researchers in their sister discipline approached, and perhaps even solved, similar problems.

Fred Sack, of Ohio State University, opened the first session with the comment that "biological responses to physical forces is a subtext to the entire meeting." Noted Sack "[The conference deals with] how physical forces interact with cells. At the most fundamental level, these are the forces on proteins. At the intermediate level, these are responses within cells to forces. At the top level is the behavior of cells (parts of the cell or the whole cell) in response to forces. [Such research includes] force transmission across the cell

Kidney cells have been cultured in low Earth orbit to study protein expression as an approach to treating kidney disease and to study the genes involved in controlling cellular differentiation. Pictured here are renal cortical cells grown on STS-90 in April 1998.

membrane and the role that gravity contributes to these forces."

Cell culture technologies focused mainly on using rotating wall bioreactors to study cell growth under gentle suspension. Using rotating wall bioreactors allows researchers to better see how cells behave with reduced mechanical stress, more like how the cells behave in the human body.

In the area of cell movement and the cytoskeleton, studies focused on the role of gravity in the transport of plant hormones, changes in the cytoskeleton, cell locomotion, T-cell activation, embryonic cell migration, and plant root growth. Understanding these aspects of cell form and function will help advance the field of tissue engineering.

Researchers presenting papers under the topic of models in lower organisms discussed experiments related to studying pathogens in order to better understand human disease. Studying these types of cells may lead to such advances as learning how bacteria behave under microgravity conditions and how much of a threat they might be to astronauts.

Additional papers presented results from studies of cell proliferation and differentiation under microgravity conditions, including the effects of microgravity on fetal cell differentiation and on tissue growth. Researchers also presented results of studies of the effects of microgravity on gene expression and on tissue growth, specifically of tissues grown for medical research.

Other papers related to another area of medical research, immunology. Because evidence suggests that spaceflight results in reduced immune function in astronauts, immunology is an area of great interest to NASA. Talks covered the effects of microgravity on gene expression in cancer cell lines, on dendritic cells (cells that present antigens — markers capable of stimulating an immune response — to T cells, a type of white blood cell that works to destroy bacteria and viruses), and on cellular immune responses in general.

A spirit of cooperation was evident throughout the meeting, as attendees asked insightful questions of presenters and made suggestions for additional avenues of experimentation based on their own research experiences and results. This kind of interaction is a model for the research synergies NASA hopes to achieve with its newest enterprise and is a promising indicator of the progress to date in forging an interdisciplinary, integrated approach to science.

Combustion Research Sparks Innovation on Earth and in Space

Funding and budgets were the hot topics at the Sixth International Combustion Workshop, which was held in Cleveland, Ohio, May 22–24, 2001. This biennial conference, attended by more than 250 scientists from the United States and abroad, provided a venue for NASA-funded principal investigators (PIs) to share their research with their peers as well as for scientists from American research institutions to obtain information on budget concerns and limited near-future funding opportunities.

Some of those research opportunities have been cut for the short term, according to Kathie Olsen, NASA's chief scientist and the acting associate administrator for the Office of Biological and Physical Research (OBPR), which oversees combustion research. She explained during her plenary lecture that because of cost overruns in both the International Space Station (ISS) and space shuttle programs, the Office of Space Flight (OSF) has had to make cuts, and these cuts have affected research facilities that are planned for the ISS, including the Combustion Integrated Rack (CIR). The budget for physical sciences research facilities aboard the ISS is still included in the budget for the OSF through the 2001 fiscal year.

Olsen cited heightened public interest in and a corresponding budget emphasis on health issues as another reason why federal dollars might be diverted from space research in the physical sciences. "But," said Olsen, "now we're starting to see a turnaround in [public awareness] that you can't have advances in health without advances in the physical sciences."

One microgravity combustion research topic in which advances being made can translate to public benefit is fire safety. Fire safety is of utmost importance in all of NASA's endeavors in spaceflight and space exploration, and contributions made to fire safety in space frequently advance methods of preventing, detecting, and suppressing fires here on Earth. Additionally, combustion research plays a major role in finding solutions to today's energy crisis, not only in terms of pollution control, which makes the air healthier to breathe, but also in terms of development of alternative sources of energy. The shift in public awareness will likely work in favor of combustion research funding in the near future. Plus, beginning in fiscal year 2003, the OBPR will have an independent budget that will include funding for combustion research.

CIR Extinguished

In the meantime, according to Olsen, the research integration budget has been cut by $800 million, or approximately 37 percent. Said Olsen, "We are working to see what we can do within that budget... [while also] ensuring that we will maintain our science."

What does this mean for combustion researchers? The Combustion Integrated Rack is "no longer in the box," said Olsen. The CIR is a modular rack designed for the ISS. It features a 100-liter combustion chamber, which can be adapted for a variety of combustion experiments, with eight replaceable windows, a gas chromatograph for analyses, and a filtration system for cleanup of combustion products before they are exhausted into space. Olsen did remind researchers that the EXpedite the PRocessing of Experiments to Space Station (EXPRESS) racks will still be available, as will the Microgravity Science Glovebox, both of which can house combustion research.

The Fluids Integrated Rack (FIR) also remains in the budget. Said Olsen, "While no combustion experiments are currently planned [for the FIR], there will be a possibility for reassigning some of the combustion experiments to this facility." She noted that such plans are only tentative.

It is possible that the CIR will still make it to the space station, just at a later date than was originally planned. Although there is no money in the budget now for the CIR, it is possible that money in future budgets could be used to "buy back" the CIR at a later date. Additionally, the European Space Agency (ESA) or any of NASA's other partners in building the space station may choose to develop such hardware jointly with NASA.

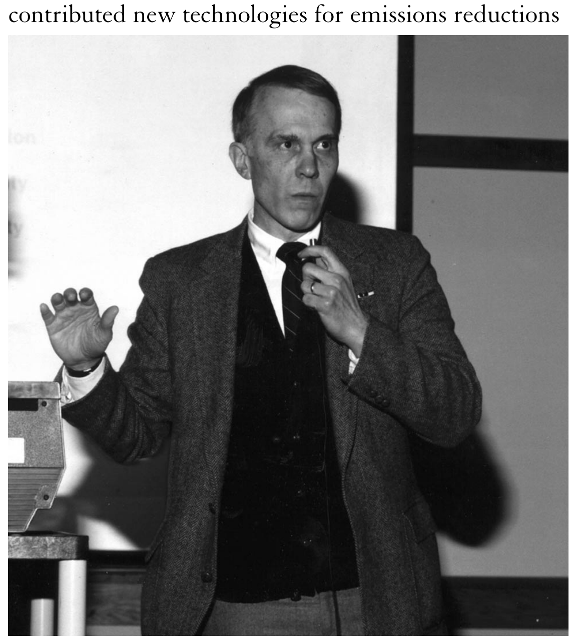
At Olsen's request, Eugene Trinh, director of OBPR's Physical Sciences Division, the division that houses the microgravity combustion program, added his thoughts in response to a question from the audience: "We will not make the mistake of letting current events drive the long-range benefits to the country of combustion research. We have not given up hope that [the CIR] is over the horizon in later years. The program will not be modified in a significant manner."

(Editor's note: Since the time of the conference, Congress has been addressing the possibility of including the CIR in the budget for fiscal year 2002.)

Keeping the Fires Burning

Other NASA representatives also emphasized that combustion research has an important place in NASA's overall space program as well as in everyday life. The health and safety of station and shuttle crewmembers is NASA's number one priority, and combustion research contributes to fire safety in space and on Earth. In response to another question from the audience after Olsen's talk, NASA PI Gerard Faeth, a professor at the University of Michigan, remarked, "There are three individuals in space who, as we speak, are in an environment that is an unusual fire hazard." Added Olsen, "[We can] say 'Look, it's safe up there, and it's safe because of our research. And we don't have a problem, because of our research.'"

Here on Earth, combustion research has also been beneficial. In his plenary talk, Donald Campbell, director of Glenn Research Center, noted, "We have contributed new technologies for emissions reductions



Principal Investigator Gerard Faeth, a professor at the University of Michigan, notes that the environment of space "is an unusual fire hazard."

for gas burners that might be used in home heating systems. We're also providing contributions in combustion diagnostic technology using normal-gravity combustion research." If the public is aware of the benefits of combustion research, then Congress is more likely to continue allocating funds to support that research.

What can NASA PIs do to help ensure continued or increased funding for the microgravity combustion program? First of all, said Campbell in his talk, "We [must] maintain our role as a leader in combustion research." Olsen noted in her talk that combustion research on the space station will not require extensive amounts of crew time, and because the station crew might not expand beyond the current number of three, research that is not crew-time intensive will have a greater chance of being flown. Lastly, Faeth, responding to a question from the audience during Olsen's talk, commented that combustion researchers should continue to contact their members of Congress as well as NASA management to express their concern for the combustion program.

> "You can't have advances in health without advances in the physical sciences."
> — Kathie Olsen,
> NASA chief scientist

PIs should also keep in mind the long-term goals of the combustion research program as enumerated by Merrill King, enterprise scientist for microgravity combustion science, during his plenary lecture. The first goal is to meld microgravity space experiments with ground-based studies, using gravity as an added independent variable to provide a better mechanistic understanding and more rigorous testing of analytical models. The second is to use basic research to provide technological advances in various combustion processes and devices. The third is to build the understanding that will permit lessons learned in microgravity combustion experiments and modeling to be used for optimizing terrestrial combustion devices. The fourth is to provide quantum leaps in the areas of fire safety and economical minimization of combustion-generated pollution. The fifth is to provide the understanding that will permit the efficient use of alternative fuels. And the last goal is to develop a better understanding of various combustion synthesis processes to open the door to the production of novel tailored material on Earth and elsewhere.

The NRA

Funding for specific experiments that will support these goals comes through NASA Research Announcements (NRAs), another topic covered at the combustion workshop. Scientists learned that the OBPR is developing a new NRA structure that will entail a single annual NRA that covers all of the research disciplines. (The disciplines will have staggered due dates for proposals.) The NRA also will contain goal-oriented initiatives, which will appear as special sections within the NRA and will define specific problems that must be solved by cross-disciplinary research.

King noted that although the NRAs will now be issued annually, the total number of proposals that will be funded will likely remain the same as the number accepted during the former two-year funding periods. That is, if traditionally around 40 combustion projects were funded during the old two-year NRA cycle, then under the new system, 20 combustion projects would be funded per year, so that the total would remain 40 new starts over a two-year period.

Because the structure of the new NRA has not been finalized, King was able to give only tentative dates for its release: OBPR currently hopes to issue the NRA in late November. In the combustion area, letters of intent to propose will be due in mid-January 2002, and proposals will be due in late February 2002. Final selections will be made in late August 2002, with grant and contract placements completed by the end of 2002.

King emphasized that going to an annual NRA was not likely to reduce the number of proposals received during each cycle, which means that the number of proposals received over a two-year period will, in effect, double. This translates to a significantly increased workload for reviewers, and King presented some tips to aid researchers in preparing their proposals that will make the reviewers' jobs a bit easier and perhaps increase the proposals' chances of being accepted. (See sidebar.) μg

Tips for Writing a Proposal

Merrill King, enterprise scientist for combustion science, gave several tips to conference attendees that will maximize the chances for their research proposals to be selected for funding. He said researchers must keep in mind the proposal evaluation criteria and ensure that their proposal answers those criteria. Four of the most important of these are as follows:

1. Is microgravity of fundamental importance to the proposed study?
2. Do the issues addressed have the potential to close major gaps in the understanding of the fundamentals of combustion processes?
3. Is there potential for the elucidation of previously unknown phenomena or interactions between phenomena?
4. Are there strong, well-defined links between the proposed research and the goals of OBPR?

King also passed along advice from a proposal reviewer's perspective:

- Keep writing clear and concise.
- Proofread the text and make sure that figures are clearly marked and have appropriate captions.
- State important issues in the research explicitly.
- State the working hypothesis and the specific problems to be investigated.
- Use appendices and supplementary material judiciously — flooding reviewers with stacks of supplementary material is unfair to the reviewer as well as to the researchers who *do* limit their supplementary materials to follow the rules.

For information on the NRA, visit the OBPR Biological and Physical Research Enterprise web site at *http://research.hq.nasa.gov/code_u/code_u.cfm*.

Microgravity News, It is A-Changin'

continued from page 3

of microgravity outreach moved from NASA headquarters to Langley Research Center, which contracted Hampton University in Hampton, Virginia, to produce *Microgravity News*. In 1995, charged with getting news about the program out to more of the program's shareholders, including Congress, teachers, and the public, Hampton hired writers who would interview investigators and managers about program activities and write the stories in a magazine-like style. The newsletter mailing list expanded beyond the NASA community to include 3,600 teachers, 1,600 university professors and researchers, and science editors at major newspapers, bringing the total number of subscribers to 8,000.

In 1996, outreach oversight moved from Langley to Marshall Space Flight Center in Huntsville, Alabama, but *Microgravity News* remained with Hampton University. Coverage continued to focus on the major microgravity shuttle missions: USML–2; USMP–3 and USMP–4; the Life and Microgravity Spacelab mission (LMS); the Microgravity Science Laboratory mission (MSL); and all nine increments of the NASA/*Mir* Program from the first shuttle docking to the final evaluation of the program. Plans for the International Space Station became a regular topic, and a series introducing other national space agencies partnering in the endeavor ran over several issues.

The newsletter also reviewed the program's progress with a series on the history and future of each of the now five major disciplines (fundamental physics was added in 1997). Stories about how the program works, from NASA Research Announcement proposal selections to the restructuring of the division at NASA headquarters to the nuts and bolts of the ground-based program appeared in the newsletter. And program research themes like Mars exploration, biological research, and nanoscience became topics of major articles as the program entered into more cross-disciplinary work and refocused on new areas of research.

With the first issue of *Space Research* in the fall, this kind of coverage will continue, except the newsletter will become the vehicle for representing the research themes, the results and relevance, and the long-term vision of the entire OBPR Enterprise. Hampton University's *Microgravity News* staff is honored to have been given this new mission. We are committed to ensuring that the expanded newsletter continues to reflect the best in all the discoveries that a microgravity environment makes possible.

— Kathy Rawson, Project Manager
Hampton University Microgravity Outreach μg

NRAs

The Physical Sciences Division plans to implement a single annual NASA Research Announcement (NRA) that will include all of the physical sciences disciplines in thematic areas of research. Release of this NRA will occur in early fiscal year 2002. Staggered due dates will be used for proposals in the various disciplines and for special-focus theme proposals. For additional information on research opportunities through the Office of Biological and Physical Research (OBPR), visit the OBPR's web site at *http://research.hq.nasa.gov/code_u/code_u.cfm*. □

Biotechnology

A new NRA in microgravity biotechnology will be issued in late fall 2001. Proposals will be due in the spring of 2002. □

Fluid Physics

Proposals for the most recent NRA in microgravity fluid physics were due on May 11, 2001. Selections will be announced no earlier than October 15, 2001. For more information, contact Gerald Pitalo, enterprise scientist for fluid physics at NASA headquarters; e-mail: *gpitalo@hq.nasa.gov*; phone: (202) 358-0827. □

Materials Science

An NRA in microgravity materials science was released in August 2001. Featured research topics solicited by the NRA include radiation shielding and biomaterials. Notices of intent are due September 25, 2001, and proposals are due November 27, 2001. □

International and Interdisciplinary

Selections for funding under the OBPR Announcement of Opportunity for Microgravity Flight Research Opportunities on the International Space Station, which was released in November 2000, will take place in September or October 2001. For additional information, visit *http://research.hq.nasa.gov/code_u/nra/current/AO-00-OBPR-01/index.html*. □

Meetings and Events

Biotechnology

Biotechnology Principal Investigator (PI) Alexander McPherson, of the University of California, Irvine, conducted a workshop on atomic force microscopy (AFM) of crystal surfaces at the **2001 Annual Meeting of the American Crystallographic Association.** The meeting, which was held in Los Angeles, California, July 21–26, 2001, helped to promote interaction among scientists who study the structure of matter at atomic or near atomic resolution. During his talk, McPherson explained how AFM has proven useful for analyzing the mechanisms and kinetics of crystal growth, especially with regard to the growth of macromolecular crystals. Information about the conference may be obtained from the meeting's web site at *http://www.hwi.buffalo.edu/ACA/ACA-Annual/LosAngeles/LosAngeles.html*. □

The **15th Annual Protein Society Meeting** was held July 26–28, 2001, in Philadelphia, Pennsylvania. The Protein Society promotes interactions among investigators as they explore all aspects of protein molecules. Information about the meeting can be found on the World Wide Web (WWW) at *http://www.faseb.org/meetings/protein01/*. □

The **2001 Annual Meeting of the American Society for Gravitational and Space Biology** (ASGSB) will be held in Alexandria, Virginia, November 7–11, 2001. ASGSB disseminates information on gravitational and space biology research and the application of this research to terrestrial and space biological problems. Researchers from government, academia, and industry use the annual meeting as a forum for communicating their research on gravity and other environmental factors in space and their effects on terrestrial flora and fauna. For additional information, visit the ASGSB meeting web site at *http://asgsb.org/annual_meeting.html*. □

Experimental Biology 2002 will be held April 20–24, 2002, in New Orleans, Louisiana. This meeting serves as a forum for microgravity researchers in biomedical and life sciences who seek through their research to improve human health and productivity, to communicate their experimental results to the science community. Information on the submission of abstracts and registration are available on the Federation of American Societies for Experimental Biology web site at *http://www.faseb.org/meetings/eb2002*. □

The **28th Annual Meeting of the Society for Biomaterials** will be held in Tampa, Florida, April 24–28, 2002. The annual meeting is held to disseminate information on research (including microgravity research) in the discipline of biomaterials — synthetic, natural, and biological materials— and on their uses in medical and surgical devices. For more information, visit the meeting's web site at *http://www.biomaterials.org/meetings/2002/index.htm*. □

Combustion Science

The **2001 Sixth International Microgravity Combustion Workshop** was held May 22–24, 2001, in Cleveland, Ohio.

Please see the article on page 8 for coverage of this meeting. □

Glenn Research Center (GRC) in Cleveland, Ohio, recently held a workshop titled **Research Needs in Fire Safety for the Human Exploration and Utilization of Space**. The workshop was organized by Gary Ruff, of GRC, and jointly hosted with the National Center for Microgravity Research on Fluids and Combustion and was held in Cleveland June 25–26, 2001. Approximately 50 people from NASA, the Federal Aviation Administration, the National Institute of Standards and Technology, the U.S. Navy, the U.S. Air Force, and the aviation and aerospace industries attended three working groups on fire prevention and material flammability, smoke and fire detection, and fire and post-fire response. Information on the workshop may be obtained on the WWW at *http://www.ncmr.org/events/firesafety/*. □

Fluid Physics

PI L. Gary Leal presented a plenary lecture titled "Drop Deformation, Breakup, and Coalescence in Viscous Fluids" at the **Fourth International Conferences on Multiphase Flow**. The conferences were held in New Orleans, Louisiana, May 27–June 1. They brought together researchers from various countries and numerous disciplines involving multiphase flow (substances of different phases, or states of matter, flowing together) to promote the exchange of new ideas, experimental techniques, and results. Several keynote addresses during the conferences were presented by other microgravity PIs. Details of the meeting can be found on the web at *http://boss.me.tulane.edu/ICMF/*. □

PIs Eckard Meiburg, of the University of California, Santa Barbara, and Anthony Maxworthy, of the University of Southern California, presented papers at the **International Workshop on Miscible Interfaces**, which was sponsored by NASA and the Centre Nationale d'Etudes Spatiales (the French National Center for Space Studies). Both investigators also served as members of the workshop's scientific committee. The objectives of the workshop were to offer a venue for presenting new findings in the area of miscible fluid flows (the flow of fluids that are capable of being mixed together) with steep concentration gradients, to encourage communication between communities that work on different aspects of miscible fluid flows, and to attract participation from graduate students working in the field. The meeting was held July 2–5, 2001, in Paris, France. Information on the meeting may be obtained on the WWW at *http://www.pmmh.espci.fr/workshop/confmiscible.html*. □

Fundamental Physics

The **2001 Annual Workshop for Fundamental Physics in Microgravity** was held in conjunction with the **Pan-Pacific Basin Workshop on Microgravity Sciences** in Pasadena, California, May 1–4. For additional information, see the listing under "International Meetings," as well as the article on page 4. □

Materials Science

The **National Space and Missile Materials Symposium**, which had the theme "2001: A Materials Odyssey From Laboratory to Space," was held June 25–28 in Monterey, California. The symposium brought together the national materials and materials processing communities to review critical technical challenges in materials, processes, and associated manufacturing that face future-generation space and missile systems. Conference sponsors included Marshall Space Flight Center (MSFC), Langley Research Center, Johnson Space Center, GRC, Goddard Space Flight Center, and Ames Research Center. John Rogacki, director of space transportation at MSFC, was a plenary speaker. A number of NASA researchers also presented papers or posters at the symposium. For additional information, visit the symposium's web site, *http://www.usasymposium.com/space2/index.htm*. □

The **2001 Electronic Materials Conference**, sponsored by the Electronic Materials Committee of the Minerals, Metals, and Materials Society, was held June 27–29 in Notre Dame, Indiana. The conference provided a forum for topics of current interest and significance in the areas of preparation and characterization of electronic materials. Among the invited organizers for this conference was Phil Neudeck, of GRC. Robert Okojie, also of GRC, was a session chair. For additional information, visit the conference web site at *http://www.tms.org/Meetings/Specialty/EMC01/EMC01.html*. □

The **13th Annual Conference on Crystal Growth and Epitaxy** was held August 12–16, 2001, in Burlington, Vermont. The conference enabled researchers to present and discuss recent research in all aspects of bulk crystal growth and epitaxial thin film growth, with sessions integrating fundamentals, experimental and industrial growth processes, characterization, and applications. NASA was a sponsor of this conference, and sessions of interest to NASA researchers included "Microgravity

Growth," "Nanotechnology," and "X-Ray Diffraction for Crystal Perfection and Growth." For additional information, visit the conference's web site, *http://www.crystalgrowth.org/accge13/*. □

Interdisciplinary Meetings

The **Gordon Research Conference on Condensed Matter Physics** was held June 17–22, 2001, at Connecticut College in New London, Connecticut. PI Paul Chaikin, of Princeton University, served as chair of the conference, which was organized by the microgravity fluid physics program. GRC participated as well. The conference covered topics ranging from biophysics and soft condensed matter (the physics of polymers, colloids, and granular materials) to quantum electronics and transport, bringing together researchers in academia and industry to discuss the most exciting and important discoveries of the past two years. For additional information, visit the conference web site at *http://www.grc.uri.edu/programs/2001/condense.htm*. □

The Gordon Research Conference on Gravitational Effects in Physico-Chemical Systems: Interfacial Effects was held July 8–13, 2001, at Colby-Sawyer College in New London, New Hampshire. Paul Steen, of Cornell University, served as chair of the conference, which was supported by NASA's Physical Sciences Division fluid physics program. Several NASA microgravity scientists and PIs presented papers or were discussion leaders at this conference. For additional information, visit *http://www.grc.uri.edu/programs/2001/gravphys.htm* on the WWW. □

The **20th International Microgravity Measurements Group (MGMG) Meeting** was held August 7–9, 2001, in Cleveland, Ohio. The meeting was sponsored by the Physical Sciences Division and provided a forum for an exchange of information and ideas about various aspects of microgravity acceleration research in the NASA Microgravity Research Program. For additional information, contact Richard DeLombard at GRC; e-mail: *Richard.DeLombard@grc.nasa.gov*; phone: (216) 433-5285; or visit the MGMG web site at *http://www.lerc.nasa.gov/WWW/MMAP/PIMS/MGMG/mgmgmain.html*. □

The **Microgravity Transport Processes in Fluid, Thermal, Materials, and Biological Sciences Conference II** will be held in Banff, Alberta, Canada, September 30–October 5, 2001. PI Satwindar Sadhal, of the University of Southern California, is serving as conference chair. Ramaswamy Balasubramaniam, of GRC; Bradley Carpenter, of NASA headquarters; and Nancy Searby, of Ames Research Center, are members of the conference scientific committee. The conference will allow scientists and engineers working in microgravity fluid, thermal, biological, and materials sciences to exchange technical information and ideas and will address the cross-cutting aspects of microgravity science and technology. For additional information, visit the conference web site at *http://www.engfnd.org/1ay.html*. □

The **Fourth Annual Conference and Exhibit on International Space Station Utilization**, which is sponsored by NASA and the Boeing Company, will be held in Cape Canaveral, Florida, October 15–18, 2001. The conference will provide an opportunity for researchers and entrepreneurs to exchange ideas and information with their peers and with space station personnel. More than 250 papers by both users of and providers for the International Space Station (ISS) will be presented in 39 technical sessions. Three plenary sessions will include presentations by space station managers, researchers who have already conducted experiments aboard the space station, and personnel involved in new commercial initiatives for the station. In addition, all of the planned ISS research facilities will be displayed in the exhibit hall.

Key speakers will include Kathie Olsen, NASA chief scientist; Roger Crouch, senior scientist, Office of Space Flight; Roy Bridges, director of Kennedy Space Center; Thomas Holloway, ISS program manager, Johnson Space Center; and Brewster Shaw, Boeing's ISS program manager. A complete list of the papers, as well as registration and logistics information for the meeting, may be found on the WWW at *http://www.aiaa.org/calendar/index4.cfm?luMeetingid=546*. □

International Meetings

The **Second Pan-Pacific Basin Workshop on Microgravity Sciences** was held in Pasadena, California, May 1–4, 2001. NASA PIs presented 60 papers at the conference. Two PIs, David Lee, of Cornell University, and Randall Hulet, of Rice University, were plenary speakers at the meeting. Additionally, the Jet Propulsion Laboratory assisted with two educational outreach events that were organized by John Emond, of NASA headquarters. For additional coverage of this meeting, see articles on pages 4 and 16. □

The **Pac Rim 4th International Conference on Advanced Ceramics and Glasses**, which will be held in conjunction with the **53rd Pacific Coast Regional Meeting of the American Ceramic Society**, will take place November 4–8, 2001, in Maui, Hawaii. The conference brings together experts from around the world to exchange key information and hold critical discussions on all aspects of advanced ceramics and glass. Sylvia Johnson, of Ames Research Center, is one of the organizers of a symposium titled "Novel Processing for Tailored Properties" as well as of the technical sessions jointly organized by the Basic Science Division and the Pacific Coast Region sections of the American Ceramic Society. Sunil Dutta, of GRC, organized the "Composites" symposium at this conference. For additional information, visit the meeting's web site at *http://www.ceramics.org/meetings/pacrimiv/*. □

The **16th Annual American Institute of Aeronautics and Astronautics (AIAA) Microgravity Science and Space Processing Symposium**, sponsored by AIAA Microgravity and Space Processes Technical Committee, will be held as part of the **40th AIAA Aerospace Sciences Meeting**. The meeting will take place in Reno, Nevada, January 14–17, 2002. The symposium focuses on issues related to materials processing in the microgravity environment of low Earth orbit, ways to measure the quality of the microgravity environment, the sensitivity of experiments to various types of disturbances, and partial-gravity science in support of future space exploration and in-situ resource utilization.

The symposium will promote interactions among researchers in microgravity science and materials processing in space, hardware developers, and policy developers. Topics to be covered include the growth of electronic materials, metals, alloys, ceramics, glasses, polymers, and proteins; fluid physics; and heat, mass, and momentum transport phenomena. In addition, biotechnology, combustion science, acceleration measurements of the microgravity environment, and in-situ resource utilization related to low- and partial-gravity environments will be covered. For more information, contact David Chato, of GRC; e-mail: *David.J.Chato@grc.nasa.gov*; phone: (216) 977-7488. μg

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Outreach Through Time Travel: Satellites Bring Scientists, Students, and Citizens Face-to-Face

Eager young minds and curious citizens crossed cyberspace time zones May 2 to learn from NASA scientists and astronauts about research taking place in space. Live video broadcasts aired with the help of satellite uplinks from the California Science Center, in Los Angeles, California, allowed close to 800 students and adults to participate in real-time discussions about a variety of topics, from why scientists conduct research in microgravity to why astronauts get "Moon face," a rounder, fuller face caused by fluid shifting to the upper body when the astronauts are in orbit. Participants were located at science centers on the East Coast, in the Midwest, in Hawaii, and at a university in Australia. They were all beneficiaries of NASA's efforts to increase awareness of careers in science and mathematics and ways in which members of the general public can be involved in NASA science programs.

John Emond, lead NASA coordinator for the event, said, "I believe these education and outreach sessions represent wonderful steps taken to engage students and the general public in active discussions about space and space research, and what they mean to us on Earth."

The special sessions were part of the Second Pan-Pacific Basin Workshop on Microgravity Sciences held in nearby Pasadena, California. The workshop afforded microgravity scientists from Japan, Russia, the United States, and other countries along the Pan-Pacific Basin the opportunity to learn from one another about the latest research being conducted in low gravity. The two live broadcasts held at the science centers — one that was education-focused and one that was outreach-focused — offered similar opportunities to students and members of the public, respectively, as current and former astronauts talked about their spaceflight experiences and some of the scientists from the workshop explained their research.

Less than one second of freefall from the top of this drop tower was all it took for denser liquid to form a sphere within a less dense liquid (at DuPont Manual High School, in Louisville, Kentucky). This phenomena that occurs in microgravity was one of the concepts that NASA scientists helped students understand the day before the uplinks.

A Field Trip to the Stars

In the morning education session, about 300 students on location at four science centers learned about career choices related to research in space, and how that research can later benefit life on Earth. For this session, the California Science

Center hosted more than 100 local high school students as well as three panelists: William Johnson, a materials scientist at the California Institute of Technology; Joan Vernikos, a biologist and retired director of NASA's Life Sciences Division; and Bernard Harris, a physician and former astronaut. Students located at the Center of Science and Industry (COSI), in Columbus, Ohio; the Louisville Science Center, in Louisville, Kentucky; and the Liberty Science Center, in Jersey City, New Jersey, also participated in the discussion by means of satellite video.

During the education session, students at the Center of Science and Industry, in Columbus, Ohio, showed participants at the other science centers that in microgravity, bubbles of carbon dioxide in ginger ale do not float to the surface because buoyancy is minimized.

Johnson, the first panelist to speak, got the students' attention by demonstrating the unusual qualities of a metallic glass he had developed through research in microgravity. The material, a metal alloy cooled so quickly that no crystals form as it solidifies, is stronger and more resilient than other metals. When Johnson dropped a cherry-sized steel ball about a foot onto a surface made of the metallic glass, the ball began bouncing and continued to bounce, unaided, for a full minute, while he continued his presentation. He told students that a metallic glass golf club, which is just one early application of this technology, transfers extra energy to a golf ball. The club can send a golf ball up to 30 yards farther than it would travel when hit with clubs made of other materials such as titanium. Johnson suggested that academic preparation for a materials science career would include a focus on math, particularly physics and chemistry, and courses in communication skills.

Vernikos emphasized the importance of curiosity and problem-solving skills in science. She said that scientists ask about the role gravity has in the evolution and development of living systems. She added, "We can't study what gravity does without going to [the microgravity environment of] space. Just as we know that in order to study the effect of light on plants we must put them in the dark, to study the role of gravity, we need an environment without gravity." Vernikos told the students that scientists also want to learn more about how to use gravity to our benefit on Earth, to strengthen bones and muscles, for example. She added that the full effects of long-duration spaceflight on human physiology are not yet known. Numerous experiments — including some by young students — are helping scientists understand the effects of microgravity on living systems. For example, in coordination with a flight experiment investigating mustard plants on STS-87, thousands of students in Ukraine and the United States simulated the investigation in the classroom, and then discussed experiment results via a live downlink with the shuttle astronauts.

Harris then shared some of what he experienced physically during short-term flights in space, such as decreased appetite. He enlisted the help of a student from the audience to show the position of an astronaut in a space shuttle seat before and during takeoff. He had the student lie with his back on the floor, legs bent upward at the hips and again at a 90-degree angle at the knees, like a stair step. Harris said that although he had to be physically fit to fly in space, his lifelong preparation for being an astronaut was much more than physical training. He started with inspiration from his heroes (Dr. McCoy on *Star Trek*, Superman, and early astronauts), a strong education (Harris has four degrees and extensive NASA training), and a desire to pursue his dreams.

Students at all four centers, who had been prepared the day before by NASA staff with information on the effects of gravity and the benefits of conducting research in microgravity, asked questions of the panelists. They also demonstrated microgravity experiments conducted with a miniature drop tower, a device a little smaller than a phone booth that provides a brief moment of microgravity as an experiment falls freely through the tower. Students at Liberty Science Center showed that magnets in freefall repel one another much more strongly than they do when they are at rest in normal gravity. Students at Louisville Science Center used a 13-ounce weight attached to a scale with a spring to show that the apparent weight drops to 0 ounces during freefall. Students at COSI demonstrated an experiment from the Dropping in a Microgravity Environment (DIME) program, which showed that bubbles of carbon dioxide in ginger ale in microgravity do not float to the surface because buoyancy is minimized. The participants also got to see a new video featuring "man on the street" interviews with students around the world about their views on space and space exploration.

Bouncing Ideas off of Satellites

That afternoon, scientists from the Pan-Pacific Basin Workshop on Microgravity Sciences converged at the California Science Center to participate in the outreach session. This portion of the event brought together microgravity scientists and members of the general public in attendance at the California Science Center; the Liberty Science Center; the Bishop Science Center, in Honolulu, Hawaii; and Flinders University, in Adelaide, Australia. Close to 500 participants heard from Gerard Faeth, combustion scientist at the University of Michigan; Nicholas Bigelow, fundamental physicist at the University of Rochester; and Chiaki Mukai, heart surgeon and astronaut from Japan.

Faeth noted two key areas of research in combustion science, control of soot and control of

Astronaut Chiaki Mukai shared her experiences flying on the space shuttle as well as her understanding of how studies of the dramatic physical changes to a human in microgravity can help scientists understand symptoms of some medical conditions on Earth.

fire hazards. Possible applications of this research include benefits on Earth, such as decreasing gases that cause ground level ozone (smog), and benefits in space, such as mitigating the danger of fire on spaceships. As a specific example of how Earth benefits from combustion research, Faeth recounted the discovery in microgravity that a low velocity of fuel combined with a high velocity of air results in soot-free turbulent flames. He recalled that when NASA first started using the KC-135, a military version of the Boeing Company's 707 jet, for conducting experiments in short-term microgravity, the exhaust from the plane was thick with soot. After the velocity of air was increased in the combustion chamber, the soot all but disappeared.

Bigelow described the two quests of the fundamental physics program: The first is to discover and explore the laws governing matter, space, and time, such as finding out why sand piles take the shape they do. The second is to discover and understand the organizing principles of nature from which structure and complexity emerge, such as how subatomic structure reflects the structure of the universe. One of Bigelow's main areas of research relates to time, which he describes as the "heart of the way we view the world and how we measure position, speed, and navigation." His research involves using the energy states of cesium atoms as the standard for time, since they are almost perfectly reliable.

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that these bands could be used to identify that and only that particular gas), and they were even beginning to have some idea about the arrangement of subatomic particles within atoms.

It was clear that atoms were small particles and usually behaved the way particles behave, existing in a single point in time and space. But under certain conditions the atoms exhibited a "wave-like" behavior. That is, sometimes an atom exists not as a single-point object, but rather is spread out over a region of space, known as the wavelength of the atom. The exact location of the atom along the length of the wave is uncertain.

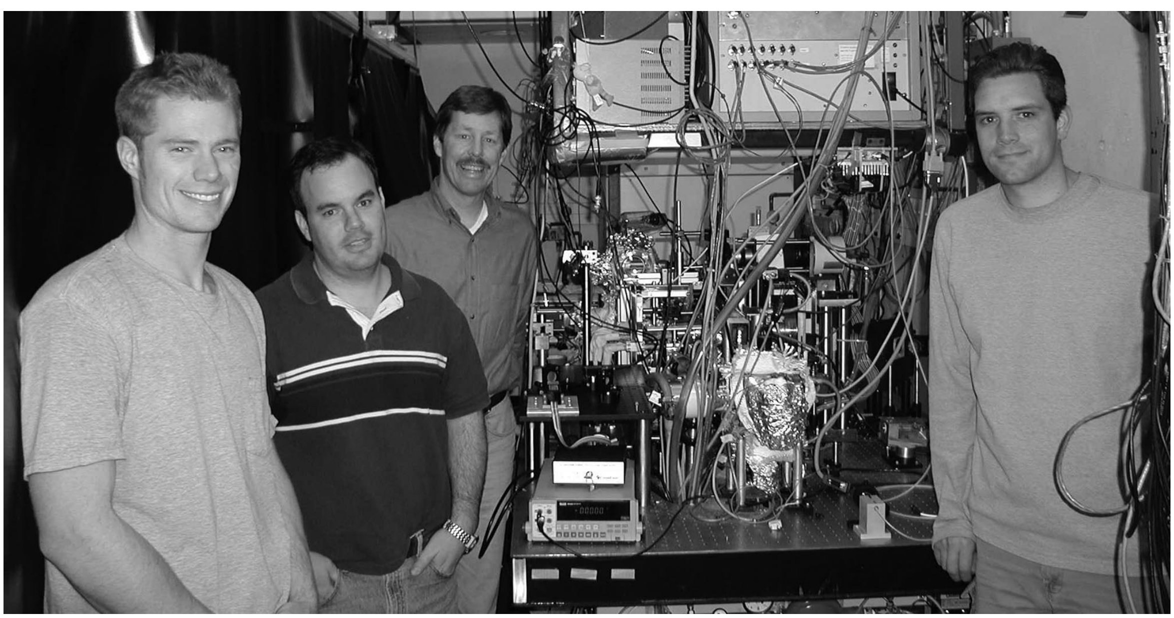
Because an atom's wave properties are inversely proportional to the speed of the atom, the slower the atom moves, the longer its wavelength — and the greater the uncertainty about the atom's position along the wave. In order to observe the wave-like behavior of an individual atom, however, scientists have to reduce the atom's speed. They do this by cooling the atom down, since the cooler the atom, the slower it moves.

Even more fascinating than the behavior of single atoms with wave-like properties is the collective behavior of atoms in large numbers under very unique and difficult-to-attain conditions. Since atoms of the same material all display the same type of wave, under unique conditions, they lock together, like troops marching in formation. At extremely cold temperatures (when the length of an atom's wave increases), dense clouds of certain types of atoms enter this lock-step formation, known as Bose-Einstein condensation. (This phenomenon is named for Satyendra Nath Bose, who formulated rules to determine when two photons [particles of light] should be classified as identical or different, and Albert Einstein, who predicted that these same rules might apply to atoms.) Bose-Einstein condensates display unusual "quantum" phenomena, including superfluidity, in which fluid substances show no resistance to flow. Dense clouds of ultracold atoms may also mimic certain classes of stars, offering insight into the reasons stars do not collapse under the force of their own gravitational attraction.

The trick of getting atoms to reveal these traits, however, lies with investigators like microgravity fundamental physics Principal Investigator Randall Hulet, of Rice University. Hulet and his research team are learning more about atomic phenomena by cooling, and therefore slowing down, these fast-moving particles. In fact, together with his team of researchers, Hulet has cooled atoms to among the lowest temperatures ever attained.

Some Like It Cold . . . *Really* Cold!

Just how cold is cold? Approximately 100 billionths of a degree above absolute zero (the value assigned as the hypothetical lowest limit of physical temperature, or approximately -273°C) is the lowest temperature Hulet has achieved so far in his laboratory. "In principle," says Hulet, "you can get arbitrarily close to absolute zero, but, of course, nobody has [actually reached absolute zero]. The



Hulet (third from left) and his team of researchers have cooled lithium atoms to among the coldest temperatures ever achieved, using a combination of laser and evaporative cooling. The object on the table covered in foil is the "atomic oven," where the experiment starts.

techniques we are using, laser cooling and atom trapping, have produced the lowest temperatures to date."

But even 100 billionths of a degree above absolute zero is still too warm for the studies Hulet hopes to conduct using atoms vaporized from the lightest of all metals, lithium. That's 10 million times colder than liquid helium, which can be used to instantly freeze most substances. "We need to get very cold," says Hulet, "and we aren't there yet." To achieve superfluidity with lithium-6 (a particular isotope of lithium), Hulet and his group will have to find a way to make the atoms five times colder than they already have.

At these almost impossible-to-imagine temperatures, pairs of lithium atoms should begin to act collectively. Hulet hopes to produce atoms with wavelengths of 3 microns (millionths of a meter), which is approximately the mean spacing between atoms in their gas. As the wavelengths increase, the atoms will overlap one another and begin to act as a single unit.

This behavior, known to physicists as collective quantum mechanics, has been studied in detail in substances like liquid helium. At 2 degrees above absolute zero, liquid helium behaves as a superfluid. It can flow through a tube the width of a minute blood vessel without any resistance. It can also climb the walls of a container or maintain a tornado-like vortex indefinitely once stirred.

Until the advent of laser cooling and atom trapping — techniques that Hulet and his team have used to cool and contain atoms — almost all materials exhibiting quantum collective effects were liquids or solids. Hulet and his co-workers, on the other hand, are studying these effects in gases. The quantum aspects of the phase transition to superfluidity are more readily revealed in gases, because the effects of strong particle interactions among atoms that are dominant in solids and liquids are minimized.

For Hulet's research, a solid piece of lithium is heated up to approximately 600°C, at which point it becomes a vapor. The lithium vapor produces a narrow stream, or beam, of lithium atoms. The laser cooling technique, which was the topic that resulted in the award of the 1997 Nobel Prize in physics to Steven Chu, Claude Cohen-Tannoudji, and William Phillips, slows them down. Laser cooling works by bombarding the lithium atoms head-on with photons of light from a laser beam. When the lithium atoms come into contact with the laser light, the light bounces off the atoms and scatters in many directions.

"Any time that the atoms scatter some of the light," explains Hulet, "they get pushed backward a little bit. Imagine that the atoms are like bowling balls and the photons are like ping-pong balls. If you throw enough ping-pong balls at an oncoming bowling ball, the ping-pong balls will eventually slow the bowling ball down and stop it. That's what we did. We kept bouncing photons off the atoms, and eventually the atoms stopped moving; that is, they cooled."

At this point, Hulet and his team of researchers need to contain the atoms in order to study their unique behavior. "But you can't just put atoms in a box," says Hulet. Remember that the natural state of lithium at low temperature is a metallic solid. "If you put them into a physical box," explains Hulet, "they would condense onto the walls of the container." Atoms stuck to the walls of the container would be of no use because this contact would cause the atoms to heat back up. "In order to avoid that," he says, "we put them into magnetic traps." A magnetic trap is a carefully arranged magnetic field that allows atoms to be suspended in space and cooled without having contact with any container wall.

A few atoms do heat up when disturbed by a chance encounter with another gaseous molecule. Although care is taken to rid the trapping container of other unwanted gases by using vacuum pumps, a random collision with a stray nitrogen molecule, for instance, will knock some of the atoms out of the trap. For the most part, however, once the atoms are cooled and trapped, they tend to stay cool for several minutes, as long as the pressure of background gas atoms and molecules is maintained below one hundredth of a trillionth of atmospheric pressure.

After the atoms have been trapped, they may be cooled to even lower temperatures. The first step is to use six laser beams, in counter-propagating pairs along three orthogonal directions, directed at the atoms, so that if atoms move in any given direction, they get a push backward from the photons of light. "It's like a viscous fluid that the atoms have to move through," Hulet describes. "Every direction that they try to move, they feel this resistance." These laser beams themselves can be precisely tuned to produce a very narrow band of light. The final step is to evaporate the hottest atoms out of the trap. This evaporative cooling leaves the remaining atoms colder, and if everything works as planned, a phase transition that produces superfluidity will be observed.

One Element, Two Flavors

Although a number of elements and compounds have been found to undergo the superfluid phase transition at low temperatures, lithium is of particular interest to Hulet because lithium exists in two different forms, or isotopes, known as bosons and fermions. Bosons, it turns out, reach the superfluid transition at higher temperatures than fermions. The difference lies in the way each type of atom can be arranged. Atoms that are fermions resist being crowded together, so only a single atom can occupy a particular energy level. The force that keeps atoms from occupying the same place at the same time is known as Fermi pressure. Bosons, on the other hand, don't have this restriction. Any number of boson atoms can occupy an energy level.

Lithium-6 and lithium-7 are each composed of three electrons and three protons; however, lithium-6 has three neutrons in its nucleus, and lithium-7 has four. These two isotopes of lithium are chemically identical, but the difference in the number of neutrons is enough to make lithium-6 a fermion and lithium-7 a boson.

Pairing Up for a Good Cause

Hulet has already seen that bosons cooled to ultracold temperatures undergo the quantum phase transition to become Bose-Einstein condensates. His challenge is to encourage the fermion atoms to also reach this superfluid transition by forming pairs with other fermions. Pairs of fermions are bosons, exhibiting the same superfluid behavior as naturally occurring bosons.

"The prediction is," says Hulet, "that you have to cool the lithium-6 atoms to near 50 billionths of a degree above absolute zero in order to see the pairing transition." Cooling the fermions to a sufficiently low temperature has proven difficult, however, because the fermions resist pairing. If this pairing could be achieved, it could help researchers better understand superconductors, explains Hulet.

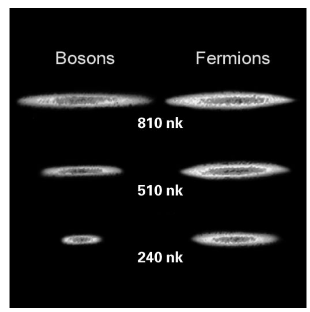
"Paired fermion atoms would give us a test bed for the theory of superconductivity, which is not at all well-understood in some situations," he says. "It will give us the ability to look at the phenomena of superconductivity in a system that we can control extraordinarily well. We can control the interactions between atoms, we can probe the atoms, and we can change the density of the atoms. That's exquisite control over a lot of different parameters. With a gaseous substance we have a kind of 'designer system' where we can fine-tune things."

Cool Thinking

An inspired technique demonstrated by Hulet and his team of researchers just might prove key to cooling the fermions to temperatures low enough for the pairing of atoms to occur. The technique involves a lithium atom cloud containing a mixture of boson and fermion atoms. The bosons, which readily respond to evaporative cooling, act as refrigerants for the fermions, which are further cooled by contact between the two isotopes.

Hulet and his team conduct their research on lithium atoms in their laboratory at Rice University. In the normal-gravity conditions in the lab, however, the clouds of atoms are big enough that their weight causes them to sag. The magnetic field in the atom trap helps to suspend the atoms, but the sagging is not completely eliminated. The distortion of the shape of the atom cloud caused by the sagging may be enough to compromise the pairing of electrons between fermion atoms that Hulet is after. "So we are not sure yet whether the experiment is going to work in gravity," he cautions. Conducting the experiment in microgravity, where the mass of the atoms becomes a negligible factor, may allow Hulet to approach the phase transition in which the fermion atoms abruptly form pairs to become superfluid bosons.

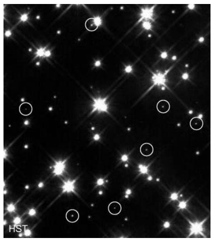
Bosons and Fermions Shed Light on Stars



Fermi pressure prevents the cloud of lithium-6 atoms (the fermions) from condensing nearly as much as the lithium-7 atoms (the bosons) as the temperature drops from 810 nanokelvins to 240 nanokelvins.

Even though mixing bosons and fermions has not created fermion pairs yet, it has given Hulet's team a snapshot of another amazing phenomenon. Images of the atom cloud containing lithium-6 and lithium-7 atoms inside the magnetic trap have revealed some fascinating insights into the forces responsible for stabilizing stars. As the cloud of atoms is cooled, it tends to fall to the bottom of the trap and shrink in size. At a temperature of 500 nanokelvins (500 billionths of a degree above absolute zero), the difference between the amount of shrinking that takes place in the bosons in the atom cloud and that in the fermions becomes noticeable. The bosons compress more because multiple atoms are capable of occupying the same energy level. The fermions, restricted from this kind of shrinking by Fermi pressure, cannot compress beyond a certain point. If cooling continues, the bosons will still shrink to a fraction of the size they were at 500 nanokelvins. The fermions will not. Fermi pressure, then, is responsible for keeping the fermions in the atom cloud from condensing further.

White dwarf stars, a type of star at the end of its life, are stabilized against collapsing from their own gravitational attraction by this same Fermi



A white dwarf star, a type of star at the end of its life, is stabilized from collapsing from its own gravitational attraction by Fermi pressure. The dwarf stars are circled in this image.

pressure, in this case produced by a high-density electron gas in the stars. Fermion atoms, even in vastly different spatial and energy scales, can exhibit the same effect responsible for stabilizing stars, which are much bigger, much hotter, and have much higher energy than the atom clouds in Hulet's laboratory.

Photographs of the atom cloud in the magnetic trap clearly demonstrate the stabilizing power of Fermi pressure on fermion atoms and the corresponding compression of the boson atoms to smaller and smaller diameters. Hulet's group is able to photograph the atom cloud by shining a laser beam through it and using cameras to capture shadows cast by the atoms as they absorb some of the light. Boson and fermion atoms, although mixed in the same atom cloud, can be imaged separately by fine-tuning the laser frequency. The lithium-6 and lithium-7 atoms respond to slightly different colors of light, so very precise adjustments of the laser beam can reveal the bosons and the fermions selectively, and each isotope can be photographed separately.

It's All in the Technique

The next step for Hulet and his team in approaching cooler temperatures for his atom clouds is to work on a different type of atom trap, one that uses a focused laser beam instead of magnetic fields. Hulet hopes that this laser trap will offer more flexibility in encouraging the phase transition that will result in the pairing of fermion atoms. "It's a technique-driven field," says Hulet. "You have to get lower and lower temperatures and higher and higher densities [of atoms]."

Hulet and his team are encouraged in their pursuits by the success they have already achieved in their experiments with lithium atoms. "There's a lot of basic fundamental physics to try to understand," says Hulet, when it comes to the behavior of atoms at low temperatures. "When we set out to use laser cooling and atom trapping back in 1991, they were still in their infancy," he recalls. Now these techniques are taking researchers ever closer to the lowest limits of temperature possible. μg

Education and Outreach

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Then Mukai, who has flown on two missions, STS-65 in 1994 and STS-95 in 1998 with astronaut and former senator John Glenn, explained how her research in microgravity relates to life on Earth. She said that she looks for how the dramatic physical changes that happen to a human in microgravity parallel symptoms of conditions on Earth. For example, studying the balance disorders, bone demineralization, cardiovascular deconditioning, muscle disuse atrophy, and decreased immune response that occur in astronauts even during short flights can lead to understanding some of the same effects that are associated with the aging process.

Mukai also spoke in very personal terms of her space experience and of her hypersensitivity to weight on her re-entry to a 1 g environment. She described her sense of wonderment at being able to feel the weight of a single sheet of paper on her hand, though this "gift" of sensitivity proved to be a fleeting one that lasted only until she readapted to the gravity of Earth.

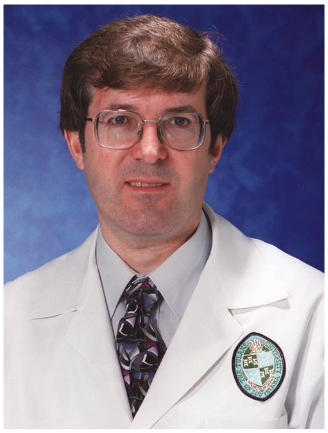
In addition, Mukai discussed the importance of psychological and multicultural issues that will arise as astronauts from countries around the world serve together on crews onboard the International Space Station. She countered, however, that although there will be differences among the crewmembers, "we have one important thing in common: we are fellow adventurers on an enterprise of discovery."

Bridging Communities

The excitement of bringing various cultures together that Mukai discussed was illustrated for session participants as they watched a video of people from Australia, China, Japan, Russia, Taiwan, and the United States featuring their viewpoints on space and space travel. Emond pointed out, "The individuals who spoke on the tape were not agency or aerospace leaders, or Nobel prize–winning scientists. They were 'ordinary people,' but as 'ordinary people' they are a key part of their respective communities and the backbone of popular support for the realm of space." He said the fact that diverse communities and cultures are expressing similar messages of a spacefaring dream on the one hand, and concern about our own planet's future on the other, is significant. He concluded, "These common visions and concerns in themselves can be seen as a bridge linking cultures, communities, and nations, the type of common interest we hope to see on the International Space Station." μg

Profile

Timothy Hammond



The career of Australian-born Principal Investigator Timothy Hammond contains a rich and dynamic blend of scientific investigation and clinical patient care, and that's just the way he likes it. While Hammond pursued a medical degree from the University of Melbourne, part-time work at the Howard Florey Institute in Australia not only helped Hammond pay his way through school, it also showed him how research could be turned into real therapies for patients in need.

"Florey," explains Hammond, "was an Australian pathologist at Oxford University who took the discovery of the antibiotic penicillin from the laboratory to commercial reality. Upon his return to Australia, Florey built a research institute dedicated to experimental medicine in physiology." At the institute, Hammond found the application of research to real outcomes for patients thrilling. "It was exciting," he says. "It was a way to help people with your skills. It was challenging and it was fun."

Hammond's interest in physiology brought him to American institutions to study and conduct research, and eventually led him to a position as a kidney transplant physician at the University of Wisconsin, Madison. Hammond's focus became the unusual susceptibility of the kidney to damage from drug toxicity. Pharmaceutical drugs that travel intravenously can often damage the kidney while leaving other organs unharmed. Proteins in the blood are responsible for this damage, as they bind toxins in the kidney tissue. "The question [was]," he says, "which proteins mediate this tissue-specific toxicity?"

In the laboratory, Hammond pinpointed the protein responsible for binding toxins in kidney tissue, but he ran into a problem culturing cells that would produce the protein. Cells grown in petri dishes develop only two-dimensionally and lose most of the specific characteristics of kidney cells. Word reached Hammond of NASA's success in growing three-dimensional cell aggregates in a bioreactor designed to study cell growth under gentle suspension. Hammond successfully applied for a grant from NASA's microgravity cellular biotechnology program and began using NASA's rotating wall vessel. He was delighted and surprised by the results: the kidney cells retained their unique features and expressed the specialized proteins.

However, there was a limitation on the amount of protein he could gather in his lab because gravity limited the size of the tissue aggregates that formed. Gravity caused the cell masses, which grow heavier as they grow larger, to eventually fall to the bottom of the bioreactor and to cease their three-dimensional growth. Taking the cell cultures to space, where the effects of gravity are negligible, would be necessary to allow Hammond to advance his research.

In 1997, a spaceflight opportunity materialized while Hammond was working in New Orleans, where he held positions at the New Orleans Veterans Administration Medical Center; the Tulane Environmental Astrobiology Center, which Hammond helped found; and the Tulane University Medical Center. Hammond flew rat kidney cells in an incubator on Russian Space Station *Mir*, and the mission was a success, producing excellent samples of differentiated cells expressing more of the sought-after protein. Although increasing the expression of the protein was an exciting step forward, the ultimate goal of Hammond's research is to understand the mechanisms (or the genes) that cause cells to differentiate and express the protein, and to find ways to control these changes.

Two subsequent spaceflight experiments have brought Hammond much closer to understanding which genes are the keys. The first was conducted on shuttle flight STS-90 in 1998. The second, flown on STS-106 in 2000, involved the teamwork of three separate NASA programs working together: the fundamental biology program, the microgravity cellular biotechnology program, and the NASA division that oversees commercial research. (Hammond shared the use of a commercial experiment facility on the shuttle.) "Three NASA programs supporting one flight was magical," says Hammond. "It's nice to work on a team where everyone wants the same outcome."

That outcome, Hammond hopes, will eventually have direct clinical implications. For example, together with commercial partner StelSys Inc., of Baltimore, Maryland, Hammond has patented a method to produce vitamin D using the rotating wall vessel in order to turn kidney implants for hormonal therapy into a reality for patients requiring renal care. "This is one of the prime examples of commercialization of NASA technology," says Hammond. And his dream is that it won't stop there. "It may be that we are going to use [International] Space Station research to bring more benefits directly to the clinical bedside. I am a big believer in basic science for science's sake. But we must also harvest the clinical benefits that we can." Hammond's countryman Florey would certainly agree.

NASA
Microgravity Research Program
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Summer 2001

Symposium Calendar

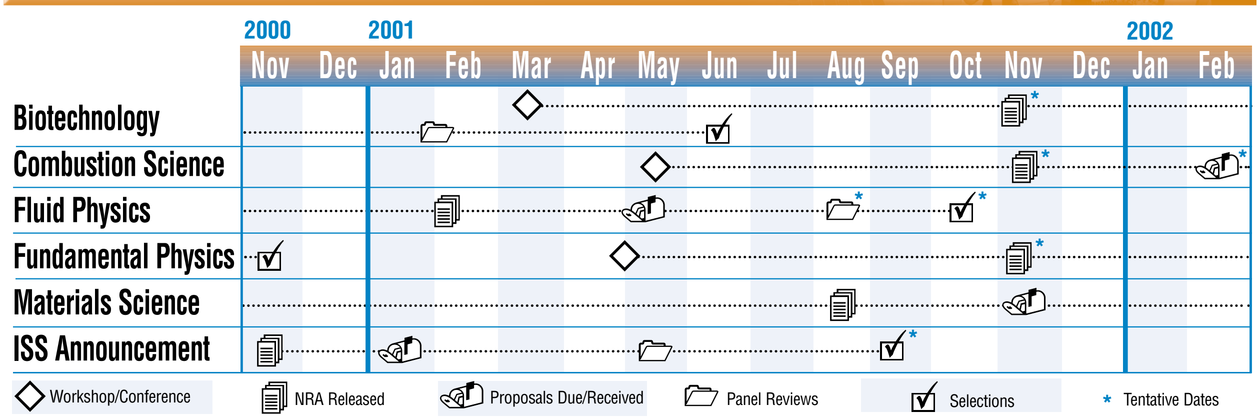
November 7–11, 2001
2001 Annual Meeting of the American Society for Gravitational and Space Biology
Alexandria, Virginia

January 14–17, 2002
16th Annual Microgravity Science and Space Processing Symposium
Reno, Nevada

April 20–24, 2002
Experimental Biology 2002
New Orleans, Louisiana

April 24–28, 2002
Annual Meeting of the Society for Biomaterials
Tampa, Florida

NASA Research Announcement Schedule



MICROGRAVITY NEWS is published quarterly by the **Marshall Space Flight Center** in conjunction with **Hampton University**. Address comments, newsletter requests, and mailing list updates to Coordinator, Microgravity Research Program Office, Bldg. 4201, SD13, Marshall Space Flight Center, AL 35812. Please provide your name, title, address, and phone number.

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